

## CONTINUOUSLY VARIABLE CONTACT LENS

## BACKGROUND OF THE INVENTION

This invention relates to contact lenses, and more particularly to continuously variable multi-focal soft contact lenses suitable for creating sharp images of far objects, intermediate objects and near objects simultaneously on the retina of a wearer, including lenses which may be used to correct for astigmatism.

There is great demand and interest in providing a contact lens that can be successfully used for both distance vision as well as for close-up reading. Currently, there are three approaches attempting to solve this problem. These approaches include the alternating vision bi-focal contact lens and the simultaneous vision bi-focal contact lens which encompasses both the right-eye/left-eye method and the blended bi-focal lens.

The alternating vision bi-focal contact lens generally has two optical zones. The first optical zone for viewing distant objects generally is in the middle of the lens. The optical zone for viewing near objects generally surrounds the first optical zone. Each optical zone is larger than the normal pupil opening so that a wearer must adapt to position the lens properly for proper application. This is a difficult task to train the patient to move the two optical zones when desired. This is particularly true with large comfortable soft contact lenses which do not move freely to switch the position of the optical zones at will. Thus, such lenses are not fully satisfactory and often the transition between the two optical zones is positioned in front of the pupil resulting in blurred vision.

Simultaneous vision bi-focal contact lenses take advantage of the ability of the human brain which has the capability of selectively choosing a sharp image when there are both sharp and blurry images projected on the retinas simultaneously. This ability to choose the sharp image leads to the two approaches using this method. In the right-eye/left-eye method one eye is fitted with a distant vision lens and the other eye is fitted with a near vision lens. The brain then selects the vision in one eye at a time. Obviously, since only one eye is used at a time the wearer loses the sense of depth perception.

The second approach utilizing the simultaneous vision bifocal contact lens is the blended bi-focal lens with one optical zone smaller than the pupil opening. This is similar to the alternating vision lens described above which has two optical zones. The distant vision zone in the center of the lens is made smaller than the normal pupil opening to insure that both optical zones are simultaneously presented to the pupil. The transition from one optical zone to the other is blended in an effort to reduce the abrupt discontinuity and glare caused by a sharp transition between zones. Notwithstanding that the transition is blended, it does not provide continuity between the two vision zones. Significantly, for any object in between the near and the far zones, two images equally out of focus will be formed on the retina that will cause confusion to the wearer.

Based on the above, it can be seen that all three approaches attempting to provide multi-focal contact lenses currently under study have severe problems which are inherent in any bi-focal lens. Because the lenses have two optical zones, one for reading and for distant vision, most anything in between, such as the dashboard of an automobile, is either blurred or forms double images, equally out of focus. Another drawback

of each of the approaches under study when applied to the more comfortable soft lenses is that it is very difficult to correct for astigmatism. Accordingly, it is desirable to provide improved continuously variable multi-focal contact lenses which overcome the drawbacks present in the prior art lenses.

## SUMMARY OF THE INVENTION

Generally speaking, in accordance with the invention, an improved contact lens with continuously varying multi-focal optical power having sufficient power within a diameter smaller than the normal pupil opening in the middle of the contact lens is provided. The desired distance vision power is at the center region of the lens and the power increases to the desired near vision power as the diameter approaches the normal pupil opening, or about 5 to 7 mm in the state to be worn for creating sharp images of far objects, intermediate objects and near objects simultaneously on the retina of a wearer. In a non-toric lens, the lens has complete rotational symmetry.

In a typical lens for a near-sighted eye the greatest power of -3 to 5 diopters at the center continuously increases to zero at the 5 to 7 mm diameter and remains at 0 diopter to the edge of the optical zone at approximately 9.7 mm in diameter. The concave surface of the lenses is aspheric and the other surfaces can be spheric, aspheric or toric.

Soft lenses are generally prepared in the hard state before expansion so that all calculations are performed using the dimensions in the dry (or hard) state, except for calculation of optical power. Optical powers for an expandable lens are calculated in the wet (or soft) state using the dry state dimensions multiplied by the appropriate expansion factor:

$$P_w = \frac{1}{\frac{r_1 \times \text{Exp}}{n-1} - \frac{t \times \text{Exp}}{n}} - \frac{n-1}{r_2' \times \text{Exp}}$$

wherein:

Exp is the expansion factor;

n is the index of refraction of the material when wet;

t is the thickness of the lens;

r<sub>2</sub>' is the radius of curvature of the concave surface at the center; and

r<sub>1</sub> is the radius of curvature of the convex surface.

The lenses in accordance with the invention are prepared by squeezing a lens blank by a ball and cutting the lens blank while held squeezed and then releasing the button after cutting and polishing. The cut and polished surface before releasing is spherical and after release it becomes aspherical. The amount of deformation created by the squeeze is measured by a micrometer which indicates the amount of displacement. A detailed procedure is set forth in our U.S. Pat. No. 4,074,469.

The concave aspherical surface generated by this method is essentially spherical from approximately a 5 mm diameter (before expansion) and out and it has a base curve radius of r<sub>2</sub>. The aspherical curve in the middle has a steeper radius than the base curve r<sub>2</sub>. The radius of curvature of this curve is the steepest at the center and is designated as r<sub>2</sub>'. The difference between r<sub>2</sub>' and r<sub>2</sub>, as well as the displacement distance between the actual curve and the spherical curve and the gradient diameter size are controlled by the amount of squeeze, the size of the ball diameter, and the depth of